Experimental Results on Current Drive by Lower Hybrid Fast Wave in VEST

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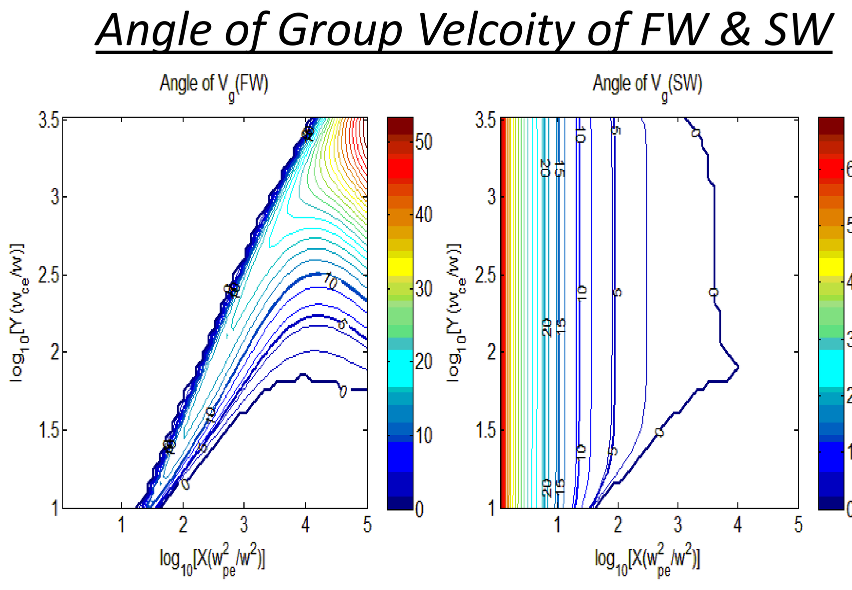
ABSTRACT

- A series of preparations and experiments have been carried out in VEST to study the feasibility of Current Drive by Fast Wave in Lower Hybrid resonance frequency range(LHFW) which could drive plasma current as efficiently as LHCD in even reactor-grade tokamak.
- A FW comb-line antenna for LHFW launcher and Klystron RF power of 10 kW at 500 MHz have been prepared and installed successfully for the study in VEST during 2015~2018.
- The LHFW is coupled successfully to VEST plasma through the antenna. The electron temperature is increased more than 3 times and about 1 kA of current is driven at coupled power of 6 kW in spite of unfavorable launching condition of LHFW.

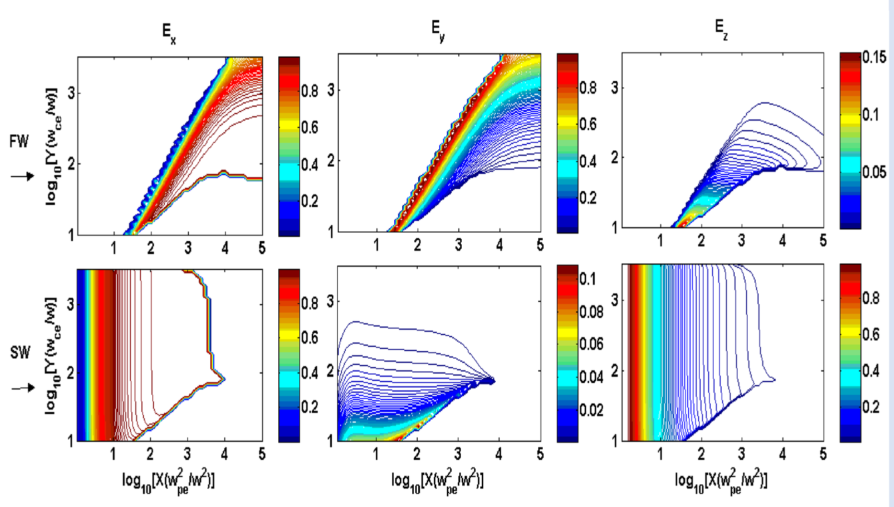
BACKGROUND

- An efficient external Current Drive is indispensable to successfully operate reactor-grade tokamak in the future. And, it is required to develop a new and innovative continuous high power and high efficiency CD method for reactor-grade tokamak such as ITER/DEMO.
- LHCD which uses slow wave in lower hybrid frequency range has very high efficiency compared to other CD scheme and successfully proved in large tokamaks such as JET and JT60-U. However, it shows the drop of CD efficiency due to high density limit.
- LHFWCD scheme use the Fast Wave instead of Slow Wave in lower hybrid frequency range because it has high penetration property in high density than slow wave and in addition it has considerable high parallel electric field for efficient Landau damping.

Angle of Group Velcoity of FW & SW



Polarization of FW & SW



CHALLENGES / METHODS / IMPLEMENTATION

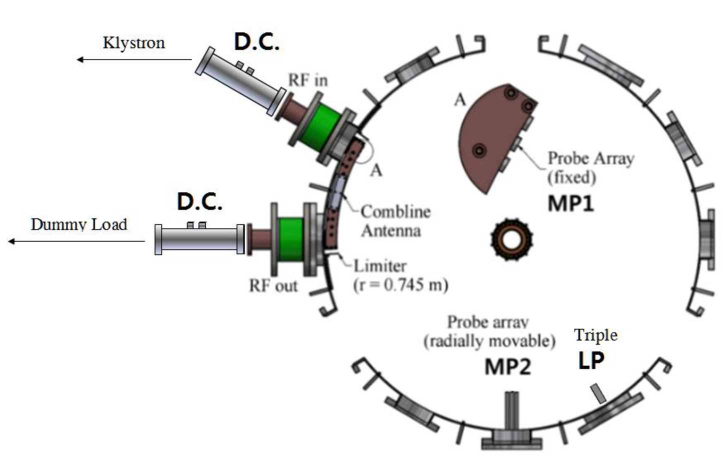
VEST(VErsatile Spherical Tokamak)

VEST is a spherical tokamak with major radius 0.45m and minor radius 0.3m.[2] The toroidal magnetic field of 0.1 T and the plasma current ranges from 25 kA upto 100 kA depending on the operation scenario. The magnetic field is upgraded to 0.2 T to facilitate NB power coupling by high density and RF current drive of LHFW by wider coupling window in 2018.

DEVELOPMENT & UPGRADE of an RF SYSTEM

An LHFW launcher of comb-line traveling wave type antenna with N = 4, RF power coaxial transmission line, and klystron of 10 kW at 500 MHz had been prepared and installed in 2017. However, the feedthrough component was damaged by multi-pactoring discharge during 2018 campaign.[3] So It was upgraded to endure higher power more than 10 kW by replacing the 3-1/8" TL with 6" TL in 2019. Antenna surface is located R = 0.75m.

RF Antenna & Diagnostics



DIAGNOSTIC SYSTEM

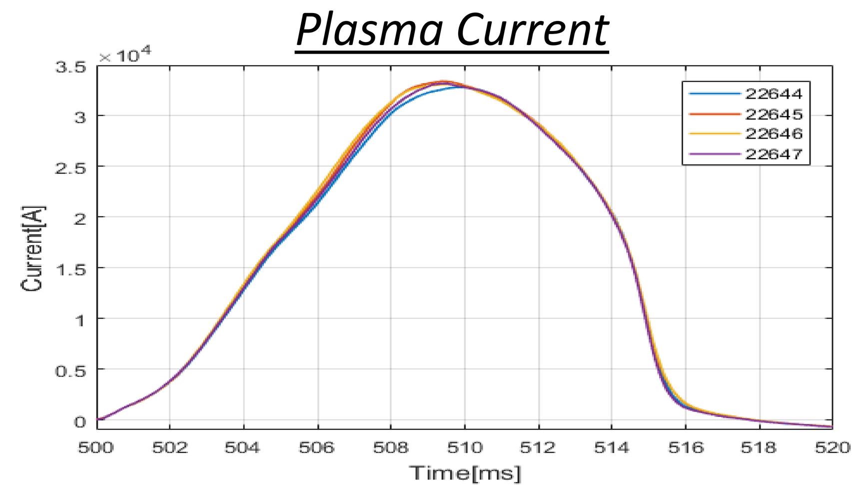
A primary diagnostic is a triple Langmuir probe installed at R = 0.75 m and 130 degree away from LHFW launcher on the same equatorial plane. The wave is measured with two MP1 and MP2 are located under antenna and 105 degree away from antenna.

OUTCOME

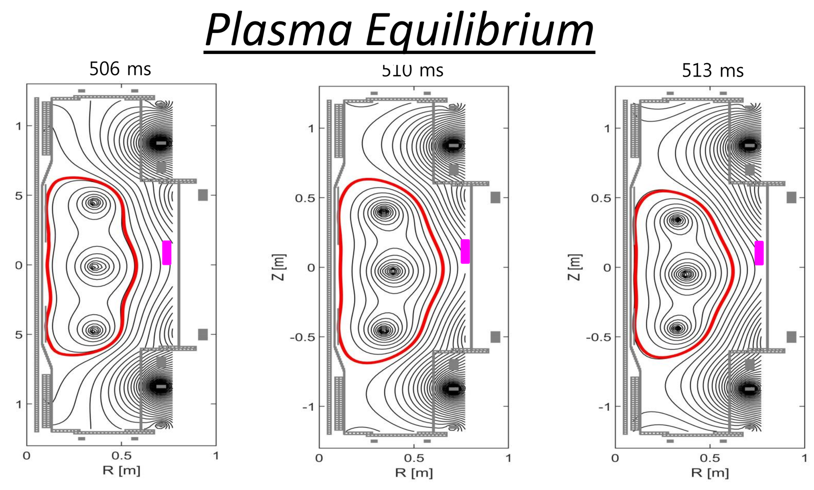
EVOLUTION OF TARGET PLASMA : CURRENT & EQUILIBRIUM & Ne/Te

The evolutions of target plasma current and equilibrium for LHFW coupling are shown in the top row of figure 3. The plasma current goes up and down with Ohmic swing power. The LCFS expands and shrinks in accordance with plasma current. Meanwhile, the time variation of electron density and temperature at edge are shown in the below. The launching and confluence density for N = 4 at B_0 = 0.15 T are plot with the density to figure out LHFW coupling and its effect on plasma parameters and current hereinafter.

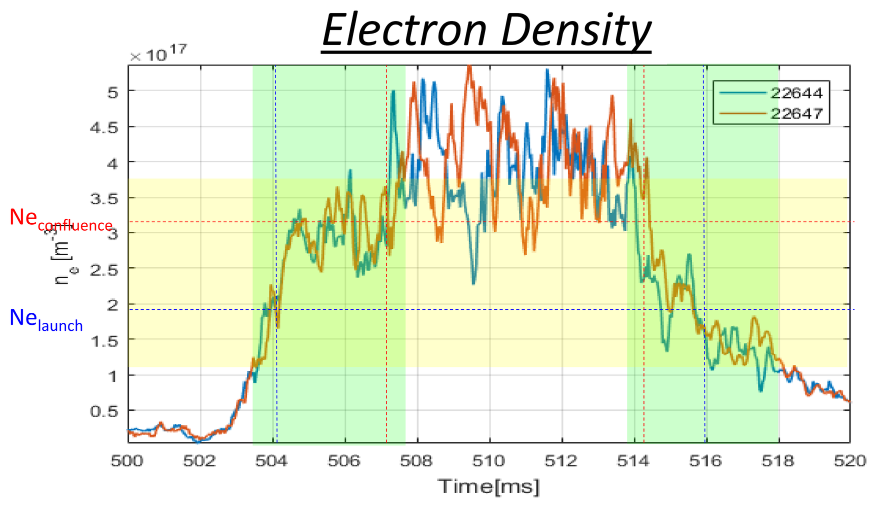
Plasma Current



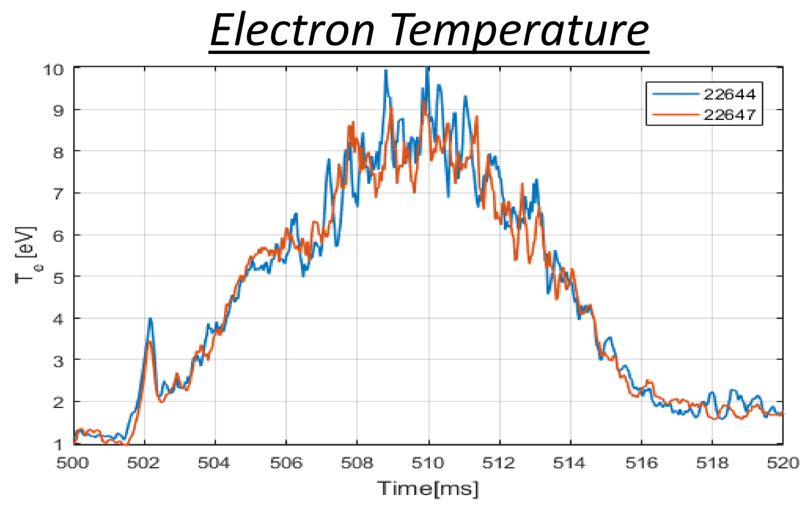
Plasma Equilibrium



Electron Density



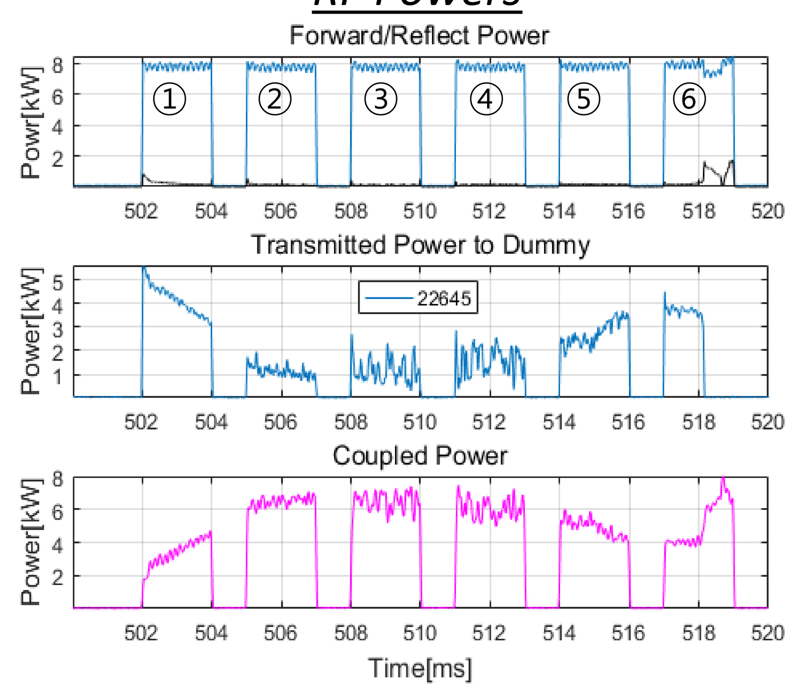
Electron Temperature



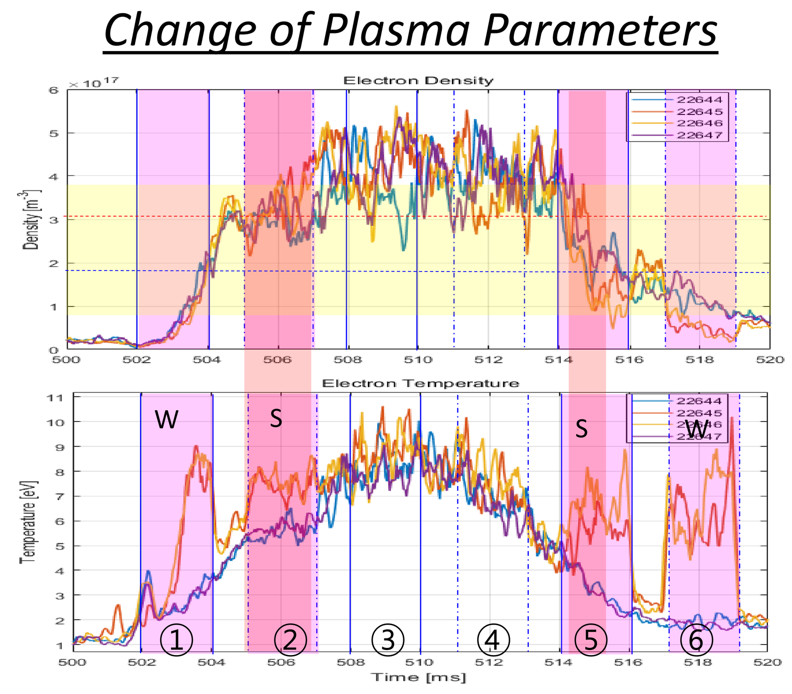
RF POWER COUPLING & CHANGE OF PLASMA PARAMETERS

RF power of 8 kW is injected into Ohmic plasma target of VEST in pulse mode. The coupled power varies from 2 kW to 6 kW with target plasma density in front of the antenna. In conjunction with the density coupling window of figure3, dramatic more than three times temperature increase is observed in pulse number 1,2,5, and 6. Higher temperature increase at relative low coupling power in pulse number 1 and 6 seems to be due to two to three times low density. The coupled power in pulse number 3 and 4 appears very unstable despite of average smoothing as predicted by the coupling window and change of plasma parameters are not observed.

RF Powers



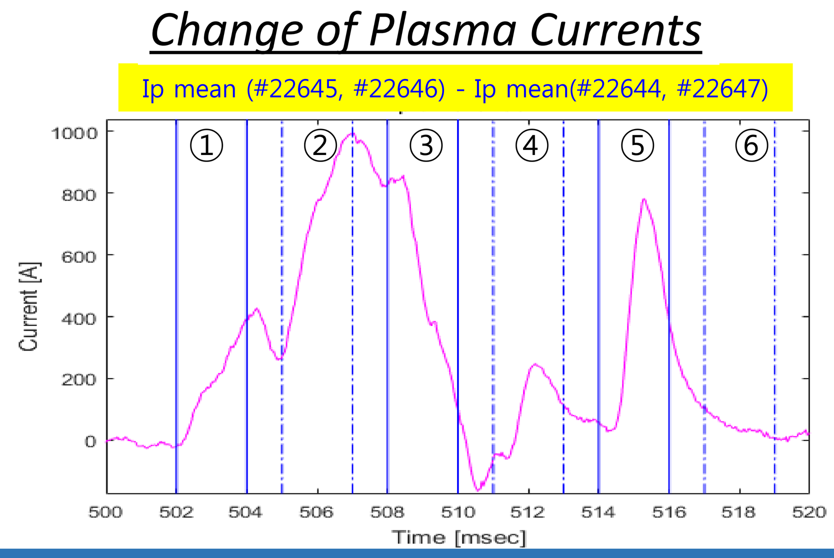
Change of Plasma Parameters



CURRENT DRIVE BY LOWER HYBRID FAST WAVE (LHFW)

The driven current is plotted with RF pulse number in figure 5. Considerable plasma current increase are observed in pulse number 2 and 5 as can be predicted from coupled power of figure4 and equilibrium shape of figure 3.

Change of Plasma Currents



CONCLUSION

- About 1 kA current was successfully driven at 6 kW coupled power by LHFW in VEST. More efficient current drive is expected in large tokamaks with wider density coupling window, controllability of ROG(Radial Outer Gap) and high temperature in the future.

ACKNOWLEDGEMENTS / REFERENCES

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