IAEA FEC 2014

Contribution ID: **73** Type: **Poster**

Optimization of High Harmonic ECRH Scenario to Extend a Heating Plasma Parameter Range in LHD

Thursday 16 October 2014 14:00 (4h 45m)

High harmonic Electron Cyclotron Resonance Heating (ECRH) is potential means of extending plasma density and beta-value ranges of fusion-relevant plasmas. Instead of the normally used fundamental ordinary (O1) and the second harmonic extraordinary (X2) modes, sufficient absorption can be expected using even O2 and X3 mode heating scenarios, when the temperature and density of a target plasma are high and the injection and/or magnetic field configurations are optimized. The cut-off densities of O2 and X3 mode wave propagation are twice and four-thirds of the X2 mode cut-off density, respectively. Moreover, the resonant magnetic field strength of the X3 mode becomes two-thirds of the field for the X2 mode.
We investigated the optimized condition of both the EC wave injection and the magnetic field configuration in the Large Helical Device (LHD). Firstly, in the case of O2 mode injection with a frequency of 77 GHz and with the optimized injection angle, about 30-40% absorption could be kept beyond the cut-off density of X2 mode, which is 3.7×10^19m^-3. Secondly, in X3 mode heating experiment, the stepwise power injection from three gyrotrons pushed up the electron temperature, leading to the absorption improvement and achieving more than 40% absorption efficiency. Superposed stepwise injection from three gyrotrons with a total of 3MW increased the central electron temperature to about 3.5 times of the initial target plasma temperature of 0.6keV. This clearly shows that the temperature increase improves the absorption rate of the subsequent injection. Thirdly, for both cases, the ray-tracing (TRAVIS) code analyses show fairly good agreement with the plasma-parameter dependences of the absorption rates experimentally obtained.
Experimental results and ray tracing analyses show also that the O2 and X3 mode ECRH can be expected as methods with sufficient absorption, when the EC beam is injected (1) along the ECR layer over a long distance in the injection case from the upper-port antenna (U-antenna case) and (2) through the saddle point of the magnetic field strength between two ECR layers in the injection case from the outer-port antenna (O-antenna case) in LHD. The high harmonic ECRH is expected to have a potential to extend the heating regime utilizing optimized injection condition and magnetic configurations with a long-distance resonance.

Country or International Organisation

Japan

Paper Number

EX/P6-34

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Session Classification: Poster 6