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Fully Non-inductive Electron Cyclotron Current Ramp-up with Focused 28GHz Beams in the QUEST Spherical Tokamak

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Electron cyclotron heating and current drive (ECHCD) system with a 28 GHz gyrotron has been prepared for non-inductive plasma ramp-up. Non-inductive plasma start-up using radio frequency waves is a key issue for advanced tokamak reactor concepts as well as for the spherical tokamak concept. A transmission line and a launcher system have been newly developed to conduct the second (2nd) harmonic electron cyclotron (EC) plasma ramp-up with an eXtra-ordinary (X) mode wave in the QUEST spherical tokamak.

There are two aspects conduct the local ECHCD experiments. One is a beam focusing, and the other is incident polarization control. The two corrugated plates (with corrugation depths of quarter/one-eighth wave-length λ) were designed to control incident elliptical polarization states, and were fabricated with careful attention to reduce Ohmic losses by means of milling, not wire-electrical discharge machining [1]. The two-mirror launcher system has been developed to obtain a narrow beam with a beam size of $w \sim 0.05$ m. The principle of least propagating-phase was considered at the mirror surface design. The Kirchhoff integral and the Gaussian optics were used to evaluate the propagating-phases before and after reflections at the mirror. The incident beam can be steered from perpendicular to tangential injections. The steering capability was confirmed at the low power test, together with the focusing property.

The local ECHCD effect was confirmed with incident polarization scanning by rotating corrugated polarizer-plates. The 140 kW 28GHz-wave with the parallel refractive index $N_{//} = 0.78$ at the 2nd harmonic EC resonance (ECR) layer was obliquely injected into the QUEST. The I_p ramp up was observed to depend on the incident polarization, indicating the local ECHCD effect. Although the 140 kW power could be transmitted with no arcing events, the arcing events were frequently detected at the polarizer section at higher power transmission. Therefore, a new quasi-optical (QO) concept of the polarizer system was proposed to avoid the arcing, and successfully implemented for higher power injections.

Figure 1 shows time evolution of the plasma current I_p , the loop voltage, poloidal coil currents I_{PF} , the Hα intensity, electron density (n_e) and temperature (T_e), and hard X-ray (HX) count and energy with the 230 kW 28GHz-wave of $N_{//} = 0.78$ at the 2nd harmonic ECR layer. The 20 kW 8.2GHz-wave was also used for the pre-ionization. The plasma current reached 80 kA, following the poloidal field ramp-up at the zero or negative loop voltages. The electron density and temperature were measured by Thomson scattering diagnostics at a major radius $R = 0.34$ m which is near the 2nd ECR layer of $R_{res} = 0.32$ m. The relatively high-density plasma (at $n_e \sim$ 2-3 x 10^{18} m^{-3}) was obtained. The right-hand cut-off density n_{cut} of the 2nd harmonic 28 GHz-wave is 2.4 x 10^{18} m^{-3} at $R = 0.34$ m for the oblique injection with $N_{//} = 0.78$ at the ECR layer. The obtained electron density was one order of magnitude higher, compared to the previous experiments with no polarized focusing-beam [2]. The electron temperature T_e decreased with the increasing n_e beyond n_{cut}, then the HX count started to increase. The HXs with 60 keV energy range were measured at the forward tangential viewing radius of 0.32 m for current-carrying electrons.

The one-path absorption rate has been evaluated with a TASK WR code [3]. Ordinary (O)- and X- mode waves were excited at the peripheral region near at the launcher. The density of the 60 keV energetic electrons was assumed to be 3 % for the whole electron density. The one path- absorption rate due to the energetic electrons would be ~ 30 % for a proper X-mode excitation with the case of $N_{//}$ = 0.78. The current ramp-up mechanisms will be investigated through controlling the local ECHCD effect by scanning the incident polarization and $N_{//}$.

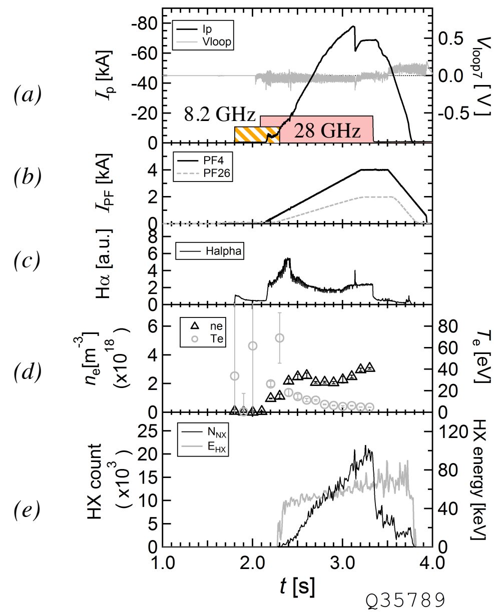

Fig.1:Time evolution of (a): I_p and loop voltage (vloop), (b): poloidal coil currents, (c): Hα intensity, (d): electron density (n_e) and temperature (T_e) and (e): hard X-ray (HX) count and energy.

References :

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