§12. Second-Harmonic ECCD Experiments on CHS


Electron cyclotron current drive (ECCD) on CHS has been investigated using high power 53.2GHz EC-wave. The final plane mirror on the power transmission system has a two-dimensional tilting mechanism so that the EC-wave beam can aim wide range of plasma volume extending both poloidally and toroidally. The power transmission system also equips a circular polarizer by which the ellipticity of injected EC-wave can be varied. In the case of toroidally oblique injection, ellipticity injection, ellipticity control is important for effective power absorption.

EC-wave beam is injected from top-port, that is, from low field side. For ECCD, k-vector of EC-wave must have parallel component to magnetic field line and that is realized by toroidally oblique injection. In simple case, magnetic field along EC-wave path increases as the wave propagates close to magnetic axis. Due to Doppler-shifted cyclotron resonance condition, electrons flowing in the same toroidal direction to the EC-wave can absorb the power so that the electrons tend to escape Coulomb-collision. Thus the heated electrons keep their momentum and that results in current drive in the opposite toroidal direction to the injected EC-wave. Fig. 1 shows the ECCD configuration and definition of beam direction \( \theta_{\text{tor}} \) and magnetic field / plasma current \( I_p \) direction (CW and CCW). Then with positive (negative) \( \theta_{\text{tor}} \) injection, driven current in CCW (CW) direction is expected theoretically. Here, \( \theta_{\text{tor}} = 0 \) is the case of pure ECH.

ECCD experiments are carried out varying \( \theta_{\text{tor}} \) position of magnetic axis \( R_m \) and direction of magnetic field. Magnitude of magnetic field \( B \) at magnetic axis on the vertically elongated poloidal cross-section is kept at 0.95T for second harmonic resonance condition with \( B_{\text{tor}} = 0 \) in spite of the change of \( R_m \) as 88.8, 92.1, 94.9, 97.4, 99.5 and 101.6cm. Variation of \( \theta_{\text{tor}} \) is limited for representative values -7, 0 and +7 degrees. Heating power source is only a 53.2GHz gyrotron and the injected power is 226kW. Polarization of the EC-wave is linear X-mode for \( \theta_{\text{tor}} = 0 \) and right-hand circular for non-zero \( \theta_{\text{tor}} \). The results are summarized in Fig. 2. Here driven current \( I_{\text{ECCD}}(\alpha, \theta_{\text{tor}}, R_m) \) is defined as \( I_p(\alpha, \theta_{\text{tor}}, R_m) - I_p(\alpha, \theta_{\text{tor}} = 0, R_m) \). The parameter \( \alpha \) represents two states of magnetic field direction, CW and CCW. Positive sign of the vertical axis means that the current is flowing in CCW direction. Currents obtained with magnetic field direction of CCW are denoted by closed symbols, and those with CW direction by open symbols. \( I_{\text{ECCD}} \) with \( \theta_{\text{tor}} \) of +7 degrees and \( I_p \) with \( \theta_{\text{tor}} \) of 0, that is, the boot-strap (BS) current are plotted. Data points for \( I_{\text{ECCD}} \) are connected with thick lines and those for \( I_p \) with thin lines just for eye-guide.

As a general feature, \( I_{\text{ECCD}} \) with negative \( \theta_{\text{tor}} \) flows in CW direction and that with positive \( \theta_{\text{tor}} \) in CCW direction in spite of the reversal of magnetic field direction, contrary to the behavior of the BS current. This is a clear evidence of ECCD. The maximum driven current in the experiment reaches almost 6kA at \( R_m = 92.1 \text{cm} \), that is, more than twice of the BS current at the same \( R_m \).

There is \( R_m \) dependence for each currents. The BS current flows in kA-order with \( R_m \) less than 92.1cm while it becomes little with \( R_m \) over 94.9cm. This dependence and the direction of the BS current qualitatively agree with theoretical prediction taking magnetic field structure of CHS. In negative \( \theta_{\text{tor}} \) case, \( I_{\text{ECCD}} \) has a peak at \( R_m = 92.1 \text{cm} \) and it decreases with \( R_m \). In positive \( \theta_{\text{tor}} \) case, \( I_{\text{ECCD}} \) is nearly zero with \( R_m \) less than 92.1cm and flows with \( R_m \) over 94.9cm.

So far the \( R_m \) dependence of \( I_{\text{ECCD}} \) has not been understood. Possible factor is magnetic field distribution along the beam path. Due to complicated helical coil winding, the distribution varies with \( \theta_{\text{tor}} \) and \( R_m \). For example, with \( R_m \) of 92.1cm, magnetic field gradually increases up to 0.95T toward the magnetic axis for \( \theta_{\text{tor}} = -7 \text{ degrees} \), while it once exceeds 0.95T and comes down to 0.95T again at the axis for \( \theta_{\text{tor}} = +7 \text{ degrees} \). Precise investigation of the dependence is a future work.

![Fig. 1 A schematic illustration showing ECCD configuration and definitions of beam direction \( \theta_{\text{tor}} \) and the notations CW/CCW.](image)

![Fig. 2 Dependence of \( I_{\text{ECCD}} \) and BS current on position of magnetic axis \( R_m \).](image)