Experimental validation of neutral beam current drive simulations in TJ-II plasmas

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Abstract
The goal of this work is the validation of neutral-beam current-drive (NBCD) calculations against experimental results in NBI TJ-II plasmas. The comparison against experimental results shows significant discrepancies between theory and experiments in NBI TJ-II plasmas.

Motivation
Precise knowledge of iota profile is needed in stellarator devices for studies such as the interaction of fast ions with Alfven Eigenmodes (AEs) [1]. Since no measurements of the iota profile are available, a detailed analysis of the plasma currents is mandatory to reconstruct the equilibrium and estimate it, especially in NBI scenarios where NBCD plays an important role.

Two NBI shots have been chosen for their relatively stable behaviour. The electron density and temperature profiles were measured using the Thomson scattering diagnostic. Ion temperatures have been estimated as in [2] and ion densities have been calculated from the electron densities assuming a flat profile of $Z_{eff}$=1.5 with a Z=5 impurity. The electric field has been taken from Doppler-reflectometer measurements [3] in scenarios with similar plasma profiles to the ones presented here. The NBI powers are 430kW and 380kW with $E_{ion}$=31.5 keV.

Simulations
The ionization of NBI fast-neutrons is simulated with BBNNBI [4] to obtain the initial distribution of fast ions. ASCOT [5] simulates the slowing down process of fast ions and obtains their distribution function.

Experimental validation of NBCD
The experimental values are obtained fitting the time trace of the plasma current to an exponential in several time intervals. The plasma current has been computed numerically and simulated with ASCOT and the electron return current was obtained by solving the drift kinetic equation (DKE) for electrons in the low-collisionality regime and for $\gamma_{beam}$=5. The DKEs code is used to calculate the contribution of the bootstrap current to the total measured plasma current. The computed current results are significantly higher than the measured ones.

Neutral Beam Current Drive
The NBCD is the result of modifying the fast-ion-beam current with the electron return current factor. This factor is calculated analytically solving the DKE in the low-collisionality limit [6]:

$$I_{NBCD} = I_{B}(1 - (A_2)) = e n_0 Z_2 V_{th}(1 - (A_2))$$

$$A_2 = \frac{Z_2 e}{T_{eff}} V_{th} \left( \frac{Z_{eff}}{Z_2} \right)$$

$$f_e = \frac{3}{4} \left( \frac{Z_{eff}}{Z_2} \right)^2 \left( \frac{T_{eff}}{T_{th}} \right)^{\frac{3}{2}}$$

$$f_i = 1 - f_e$$

$$h(x) = \Phi(x) - G(x)$$

$$\Phi(x) = \int_0^x e^{-y} d y$$

$$G(x) = \frac{\Phi(1-x)\Phi(x)}{2x}$$

Conclusions
The plasma current has been computed numerically for two NBI shots in TJ-II. The comparison against experimental results shows large discrepancies between theory and experiments. Main sources of error thought to be the absence of CX reactions in the simulations and uncertainties in the experimental measurement of the plasma current, due to poor stability of plasma current. Plasma impurities can be affecting the NBCD through the dependence of $A_2$ on $Z_{eff}$.

References